

# **The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines**

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## Summary and Conclusions

### Overview & Introduction

This study was undertaken on behalf of The Highland Council, and its associates, Scottish Natural Heritage and the Cairngorms National Park Authority, so that they might be adequately and objectively briefed on the technical, financial and environmental issues pertaining to the undergrounding of Extra High Voltage (EHV) transmission circuits. It was prepared to provide this information ahead of the formal application by Scottish Hydro Electric Transmission Limited (SHETL) to upgrade the existing 132kV Beauly - Denny transmission line to 400kV under Section 37 of the Electricity Act 1989.

Whilst specifically addressing the issues surrounding the proposed Beauly - Denny transmission line, the document provides information which will also be applicable to other 400kV transmission schemes planned for The Highlands area.

This study provides information under four main sections:-

- Review of the Technical Issues
- Generic Life Cycle Costs
- Environmental Impacts
- Case Studies

The opening section introduces the electrical power transmission technologies available, reviews the SHETL proposals for the new 400kV Beauly - Denny transmission line and updates information on projects described in two earlier reports on the costs of undergrounding EHV cable. This section also describes additional recent EHV underground cable schemes and cable installation in sensitive areas.

Section 2 provides estimates of comparative life cycle costs for cabled and overhead transmission circuits giving consideration to: capital costs, transmission losses, maintenance costs, reliability and availability (including climate and its effect on fault incidence) and decommissioning requirements.

In section 3, consideration is given to the environmental impact of undergrounding EHV transmission circuits in both upland and lowland habitats under a number of key headings. This section also provides a summary comparison of the possible environmental impacts of the two basic transmission options (overhead and underground).

Finally, section 4 is used to draw the information from the first three chapters together. Two contrasting sections of the Beauly - Denny line have been chosen as case studies for the purposes of estimating the capital and whole life costs and for discussing the environmental impacts of undergrounding in a practical situation. One case study focuses on a lowland habitat, considering a 7km section of the Indicative Proposed Route

## **The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines**

between the planned new 400kV substation at Beauly and the village of Eskadale. The other is an upland case habitat covering a 2km section of one of the Indicative Proposed Route options in the Dalwhinnie area.

The appendices include a review of two earlier reports on the undergrounding of EHV circuits and a description of the regulatory issues regarding transmission system operation and capital expenditure.

### **Summary of Findings**

#### **Technology**

In reviewing EHV cable technology the report shows that fluid-filled (FF) UGC technology is well-established at 400kV and has been used in the UK transmission system for many years. Its main drawbacks are the potential to cause environmental damage from a fluid leak and the complexity of the hydraulic systems required to maintain the insulating fluid under pressure.

The report also records that, whilst EHV UGC is mature technology, it does not offer the same level of availability as overhead line (OHL). This is partly because of the increased failure rate of UGCs and partly because of the longer repair times which characterise the cabled solution.

In recent years, cross-linked polythene (XLPE) insulation has emerged as a cheaper alternative to FF cables and this is beginning to be used by transmission network operators around the world at increasingly high voltages. Whilst XLPE cable is being specified for a number of current 400kV cable projects in the UK, this is, to date, only for projects where the cables are to be installed in tunnels. The most recent UK EHV cable project where the cables were installed in trenches, and which, in consequence, are much more difficult to gain access to in the event of a fault, was NGC's Newby - Nunthorpe scheme where FF cable technology was specified. It is therefore to be expected that SHETL would favour the use of FF cables if UGC technology was to be used for the Beauly - Denny line, particularly given the remoteness of much of the route.

The report has also briefly considered other emergent technology in the shape of Gas Insulated Line (GIL), which is not considered suitable for Beauly - Denny as, unless it were installed below ground, it too would have a significant visual impact and also because the technology is still unproven over long lengths. GIL is also likely to be significantly more expensive than an UGC solution. Superconductivity is also ruled out as an option as the technology is still at the experimental stage.

The earlier reports reviewed as part of this study are, in general, found not to be reliable sources of information. In particular, they contain a number of technical errors and some of the recent transmission projects quoted, which are suggested as employing UGCs, are actually OHL. It was also noted that some of the conclusions reached in these reports were not founded or supported by evidence and that the documents showed partiality in favouring the case for UGCs. In one of the reports, a case is also advanced that extensive use of EHV UGCs would offer a means to improve security of electricity supplies in adverse weather conditions. Jacobs Babbie does not support this conclusion

## **The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines**

due to higher fault rates and increased repair times associated with UGC technology. This current Jacobs Babbie study has also concluded that OHL installation in a hostile environment is unlikely to be a major factor in detracting from circuit availability as weather-induced faults are mainly transient in nature and OHLs can be specifically designed for application in exposed environments.

Extensive efforts were made to identify new EHV UGC transmission projects around the world with particular emphasis being directed toward Norway, Denmark and Canada. As part of this review, information was obtained to update progress with a number of recent UGC projects. From this exercise, it became clear that SHETL's approach to the use of UGCs is typical of other transmission network operators across the world in that EHV UGC technology will only be used by choice where it is shown to be the cheapest or technically most-appropriate solution.

There are a number of examples where UGC has been used because it provided the only means of obtaining planning consent for a wider transmission scheme (e.g. Aalborg - Aarhus in Denmark and Newby - Nunthorpe in the UK). UGC does, however, find widespread application at lower system voltages and it is suggested that this may give the impression that the use of UGC at EHV is more commonplace than it actually is.

Direct Current (DC) EHV transmission technology has been reviewed briefly by this study but, as the proposed Beaulieu - Denny line would provide additional connections between two points on an already interconnected transmission system, it is not a technically appropriate solution. Further detailed consideration has therefore not been undertaken.

### **EHV Cable Installation Techniques**

An introduction has been provided in the study to UGC installation techniques which records that installation in trenches is the most widespread method. Installation in pre-cast concrete troughs is an alternative which provides a more compact installation but at additional cost and with the drawback of the route being clearly delineated by the surface mounted concrete trough covers. The trenched installation of EHV cables represents a significant civil engineering project and construction would involve motorway-width disturbance and the movement, possibly off site, of considerable volumes of spoil. In lowland agricultural environments, however, restoration is very effective (and proven) and post-installation, the land retains its use for grazing and arable crop production.

No evidence of installation and restoration in upland habitats been identified as part of this project.

Installation of EHV cables in tunnels is also a practical solution with low environmental impact aside from the spoil generated by the tunnel boring activity but it is an expensive approach. As a result, the technique has only been used to overcome urban congestion and natural barriers (such as estuaries). No cases were found of tunnelling being used as a solution in environments comparable to that which exists over the proposed Beaulieu - Denny route.

## The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines

### Cost Issues

Turning to the cost issue, the study found that capital cost ratios (comparing UGC costs with OHL costs) vary significantly dependent upon the length of the cable section under consideration. A key factor in determining comparative costs is the number of joints required to connect drum-delivered lengths of cable together and of the costs of the "Sealing End" equipment, which is required where the OHL and UGC sections of a line join. Actual UGC installation costs also vary widely with terrain. Capital UGC to OHL cost ratios calculated in the study varied from 6:1 to 12:1 based on assumptions generally favourable to UGC. Calculations are included for both FF and XLPE cable systems which show that an XLPE installation could be expected to be around 30% cheaper than FF. SHETL quote a range for installation cost ratios of between 14:1 and 25:1 and it is concluded that these estimates are at the higher end of the possible ranges.

It is possible to introduce significant variance into the calculated cost ratio dependent upon which cost elements are included in the analysis. A truly meaningful cost comparison could therefore only be obtained by undertaking a detailed feasibility study on a particular section of the route where the required technical solution is clearly defined and scoped.

In researching this study, attempts were made to obtain UGC cable cost information from a range of sources but this proved to be of limited success, reflective of the relatively small number of manufacturers in the market. Transmission network operators were equally reluctant to provide cost information, claiming commercial confidentiality.

Comparing EHV cable cost data in the public domain with information obtained specifically for this study led Jacobs Babbie to conclude that UK cable procurement costs/km appear higher than those quoted for other European projects although it is not evident why this should be the case as the cables appear to be technically similar. Outline information relating to the recent Aarhus - Aalborg transmission project in Denmark, for which a headline figure cost ratio between UGC and OHL as low as 4:1 had been quoted for parts of the route, was also obtained. This did not, however, provide any additional guidance as to how this headline figure had been calculated.

Assessment of the installation technique used for the Aarhus - Aalborg project, which used XLPE-insulated cables, showed that similar trenched configurations were used to those which are found in the UK. The main difference in the approach to construction used for the Danish project was the simpler design adopted for the construction of cable joint bays (although it is felt that the approach used could lead to reliability problems in the future).

The other important feature of the Aarhus - Aalborg project was the decision taken to not match the rating of the cabled section of the route to that of the OHL. This approach allows a much smaller conductor to be used for the cabled sections, thereby providing savings on cable procurement costs. In the UK, planning standards embodied in Transmission Network Operators' licences currently preclude such an approach from being taken. This has the result that, in the UK, under normal system operating conditions, circuits run at a relatively small fraction of their total rated capacity. By way of

## The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines

illustration of this point, SHETL's winter peak demand forecast current flows in the proposed Beaulay - Denny line under assumed 2013 generation conditions are, for example, predicted to be around 1,700 amps, compared with a winter circuit rating of 3,400 amps.

When allowance is made for the different approach to cable rating, the UGC to OHL capital cost ratios quoted for the Aalborg - Aarhus project become more comparable with those calculated for the UK.

In considering the regulatory perspective on funding for the proposed Beaulay - Denny upgrade it is important to note that SHETL would recover the capital cost from their customers through Transmission Use of System Charges. These charges would reflect the capital value of the Beaulay - Denny project as agreed with the Regulator. Thus, if the capital cost of the Beaulay - Denny upgrade were to increase, for example, as a result of undergrounding a part of the route, a point would be reached at which the total capital cost of the project would be equal to the likely constraint costs<sup>21</sup> which would have to be met if the upgrade was not undertaken. At such a point, the upgrade project would cease to become viable.

The study also considered whether, when allowing for total costs over a 40 year life cycle, the cost ratio between UGCs and OHLs became lower. In estimating life cycle costs, consideration was given to losses, maintenance and decommissioning costs and circuit reliability/availability.

Transmission losses, being proportional to the square of the current flow in the line, are lower with UGC, essentially because of the larger conductor cross-section which is required. This advantage does not, however, convert to a significant lifetime cost saving because, for reasons explained above, the UGCs would not, for the majority of their operating life, be run at anywhere near their maximum rated current due to system planning constraints.

Maintenance and decommissioning costs are shown to be insignificant when compared to initial capital costs.

Information collected for the study from a variety of sources this study shows that prolonged faults are more frequent in underground cables than overhead lines and they also take, on average, much longer to repair. Prolonged outages lead to 'constraint costs' being incurred, the extent of which is determined by the following:

- the amount of generation constrained not to deliver output;
- the duration of the constraint; and,
- the price the constrained generation would have received for that output.

Calculation of such constraint costs is difficult and subjective as it requires assumptions to be made about typical outage durations, volumes of load and demand and electricity prices as inputs to the calculation. A significant element of the cost of generation will, for

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21

Payments made to generators when their output is restricted by lack of transmission network capacity.

## **The Highland Council, Cairngorms National Park Authority & Scottish Natural Heritage Undergrounding of Extra High Voltage Transmission Lines**

renewable generators, be the value of the Renewable Obligation Certificates (ROCs) which would have been earned by the generation. Difficult predictions must therefore also be made about the likely value of ROCs over the operating life of the transmission circuit. Calculations performed during this study indicate that, when including the cost of constraints in the lifecycle cost calculation, such costs could offset any savings made from the lower losses associated with UGCs. It is possible, however, to achieve a wide variation in constraint costs determined by the assumptions made in the calculations.

### **Environmental Considerations**

Turning to the environmental issues, the study notes that there are a wide variety of potential environmental impacts which must be considered when undergrounding EHV transmission circuits. As very little information on the environmental impact of EHV underground cable installation was identified during the study fewer conclusions can be drawn about UGC compared to OHL. Quantification of the environmental issues regarding undergrounding of EHV circuits requires site-specific studies to be undertaken.

In general, the construction activities associated with UGC installation have a greater environmental impact than those required for OHL construction as site durations are longer and earthworks volumes greater due to the nature of the cable installation. In the operational phase, UGC cable installations clearly do not create the significant visual intrusion which OHLs do although careful consideration must always be given to the siting of the sealing end compounds which are required where cabled sections of the route connect to OHL sections. Similar consideration must also be given to the siting of any reactive compensation equipment associated with UGCs although the latter is unlikely to be required for shorter cabled sections.

There is much evidence to suggest that reinstatement of habitats to their pre-installation condition for UGCs can be achieved to good effect in lowland, agricultural situations but for upland environments, the position is less secure due to a lack of relevant operational experience. The potential environmental impact of the heat emitted from the cable due to its electrical losses remains unquantified and this raises concerns over the effectiveness of reinstatement, particularly for peat habitats, due to the potential for drying out of the ground above the route. No relevant past studies into such effects were found by the research undertaken in the preparation of this report.